Proposal: Alternative Redesigns of Mechanical Systems

PHARM CORP.

Pills, Delaware

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Option: Mechanical

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EXECUTIVE SUMMARY

This proposal is to investigate different alternatives for a mechanical redesign for Pharm Corp., which is a headquarter building in Delaware. Information from Technical Reports 1, 2, and 3 were analyzed to determine the best potential alternatives for the building. In determining the mechanical alternatives, several factors had to be determined. They are energy consumption, overall system upfront cost and lifecycle costs, impact on the mechanical room size, and providing thermal comfort efficiently.

Using those factors, the alternatives that have been determined to investigate deeper are 1) active chilled beam system, 2) hydronic heating with natural gas boiler, and 3) condensate recovery for cooling tower use. Currently the building uses a direct expansion air-handling unit with VAVs, which is cooled by condenser water produced from a closed circuit evaporative cooling tower. Although the original system is simple and works as designed, the electrical consumption due to all-electric heating is alarming.

To determine the best alternative, each of the redesigns will be modeled in Trane Trace 700 Load simulation software, and compared back to the original design. As Trane Trace cannot determine potential recovered condensate from the system, those calculations will be conducted using excel, using equations found from research conducted. The overall objective is to maintain or improve indoor air quality and thermal comfort, while reducing the amount of energy consumption the mechanical system uses, reduces electric consumption, and lower emissions by the system.

Additionally, two breadth studies will be examined to analyze their effect from each alternative. The first breadth is electric consumption from the mechanical system. Solar photovoltaics will be designed to determine how many are needed to reduce the electric consumption by 30% in the building. As the electric demand will differ between the three alternatives, the amount of panels required will also differ, resulting in differing first costs, lifecycle costs and different payback periods.

Along with electric consumption, water consumption will be analyzed from each system. The hydronic hot water system introduces water required, while the condensate recovery system reduces potable water required by the cooling towers. Each alternative will impact the potable water required to be sent to the building, changing the water cost. Potable water amounts will be compared for each alternative, as will water amounts required as loads and water temperatures differ throughout the year.

BUILDING OVERVIEW

Pharm Corp. is a headquarter building, hosting offices and conference rooms for executive employees within the company. It is located in Delaware, with an overall square footage of 154,000 SF. It is comprised of four floors, with a 4-story grand atrium as the entrance, a large kitchen on the third floor and a large dining area with a 2-story ceiling.

The layout of the building takes on a bracket shape, with a West wing, an East wing, and a centralized core connecting the two. The line of symmetry is 22.5° from the vertical. The floors are generally the same shape, with slight step-backs on the upper floors creating natural green roof terraces.

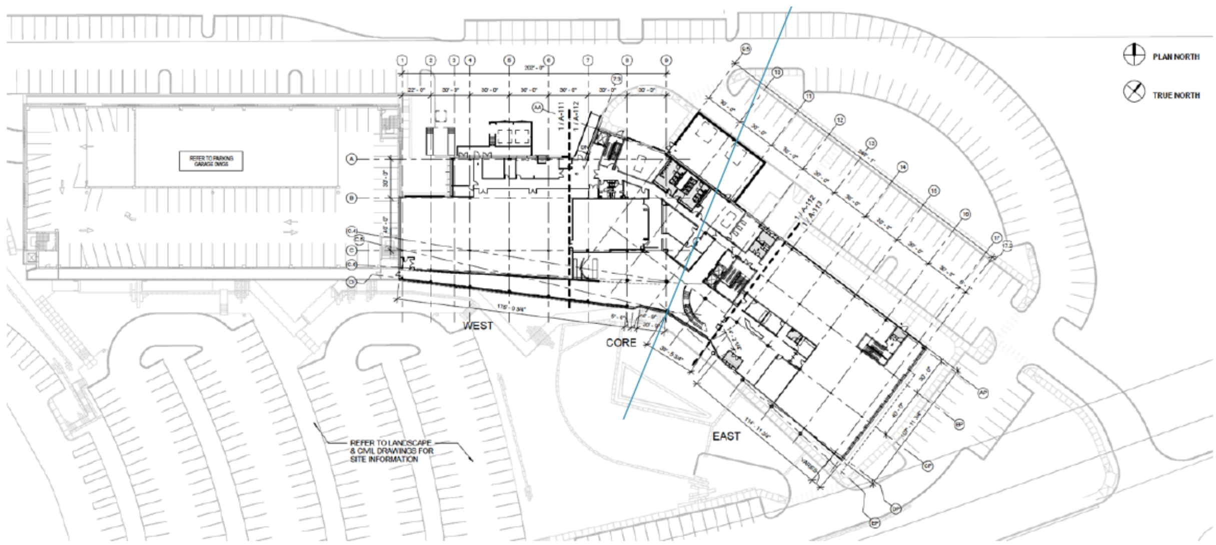

Figure 1. Site plan of building, illustrating West, Core and East, with mirror line of 22.5°.

Utilizing the architecture of the building to an advantage, the glass on the East face is tilted inward. This allows natural light to enter in the morning, naturally heating up the space. The West facing glass, however, is angled outward, rejecting direct light. Allowing light in the morning can preheat the East spaces in the winter. The West glass does not let heat gain in the afternoon during the summer when the sun is at high angles.

Adjoined to the main headquarters building is a 4-story parking garage, recessed into the ground to create a 3-level offset from the main building. This creates parking space for the employees, that can easily enter the main building by a vestibule that connects the 4th level of the garage directly into the 1st floor atrium in the main building. It reduces the amount of run-off to the site and condenses the amount of landscape that has to be disturbed by creating parking lots.

MECHANICAL OVERVIEW

The main equipment providing conditioned air to the interior spaces are air-handling units, to the office space, kitchen, and dining area, and dedicated rooftop units for the conference rooms. A summary of both the air handling units (AHU) and rooftop units (RTU) can be seen in Table 1 and 2, respectively.

Table 1. Air-handling Unit schedule.

Unit	COOLING		Heating
	Total	Sensible	Total
	MBH	MBH	MBH
AHU-1-1	467.7	155.9	232,152
AHU-1-2	374.2	124.7	116,076
AHU-2-1	467.7	155.9	232,152
AHU-2-2	421.0	140.3	232,152
AHU-3-1	647.8	187.8	232,152
AHU-3-2	421.0	140.3	232,152
AHU-4-1	389.5	129.8	116,076
AHU-4-2	374.2	124.7	116,076

Closed circuit evaporative cooling towers provide condensing water that is sent through condenser water pumps. This water is then sent to the air-handling units, which call for a desired amount of condenser water to provide proper cooling for the unit.

Table 2. Rooftop Unit schedule.

Designation	Coil	Total [BTU/h]	Sensible [BTU/h]
RTU-5-1	Heating	64,000	-
	Cooling	35.2	24.5
RTU-5-2	Heating	64,000	-
	Cooling	35.2	24.5
RTU-5-3	Heating	64,000	-
	Cooling	35.2	24.5
RTU-5-4	Heating	64,000	-
	Cooling	35.2	24.5
RTU-5-5	Heating	64,000	-
	Cooling	35.2	24.5
RTU-5-6	Heating	64,000	-
	Cooling	35.2	24.5

At the AHU, an air-side economizer controls the amount of outside air that is being brought in, based on ambient air conditions. If ambient air is able to satisfy the load, the unit may call for 100% outside air. In other cases, the economizer may only bring in the minimum amount of air that is required for conditioned space requirements. The rest of the air is then recirculated air from the zone. Controlling the airflow that is sent to the space are VAVRH boxes. Based on the temperature in the space, the VAV box will either open or close. The fan associated with the unit will increase or decrease, which is controlled by the duct static pressure sensor. If overcooling occurs, electric reheat coils are turned on to increase the supply air temperature.

As for the heating in the building, it is all resistive heating. Electric perimeter baseboard provides heat where curtain wall systems are located, reducing the heat gain and loss through the windows. Within the interior spaces, heating is controlled by the coils in the AHU or RTU.

Distribution of the air within the spaces is generally done by 24x24 diffusers, but within the atrium and the dining area, diffusers are linear, and are recessed in a sawtooth ceiling design. Figure 2, below, is the detail for a sawtooth ceiling. It is designed to hide the diffuser while providing an architecturally appealing ceiling. The star is the location of

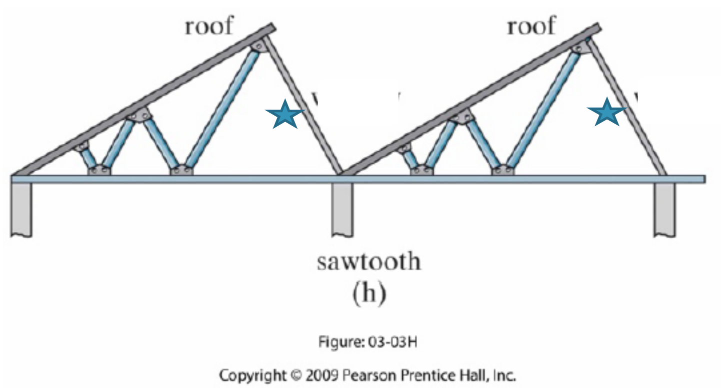

Figure 2. Sawtooth ceiling detail.

where the linear diffusers are to be placed, directing conditioned air into the space. As this figure depicts the top element as a roof, this building uses this layout so the top element is the ceiling, which is below a flat roof.

Design Objectives

Pharm Corp. had two main influences in its design that were required to be satisfied. First, the interior space has to be an efficient office space for the employees. Thermal comfort for the occupants is an obvious concern to satisfy, but limiting the noise within the space is crucial for efficient work to be done in the workspace. A comprised list of the mechanical goals for the building are listed below.

Category	***Goal***	***Strategy***
Energy	*Utilize free cooling when conditions permit.*	*Installation of an enthalpy-based airside economizer is used on all AHUs in MERs.*
Energy	*Reduce electrical load within office space.*	*All design conditions are in compliance with LEED Certified requirements, although the building is not LEED.*
Comfort	*Minimize noise disturbance from HVAC system.*	*All ducts are lined 15'-0" minimum downstream of all terminal units, and ducts leaving MER are installed with sound attenuators. Maximum NC is 40.*
Cost	*Limit ductwork that is to be installed.*	*Mechanical rooms are placed on perimeter walls, allowing louvers to bring in OA versus ducts from roof.*

Secondly, conserving the amount of energy that is used within the workplace with the mechanical system was a priority goal for the owner. The owner wanted to ensure that the system could operate efficiently, while conserving energy at all costs and maintaining comfort levels for their employees. To conserve energy within perimeter spaces, or spaces exposed to an essential amount of natural daylight, daylight response dimming controls are installed. Daylight response is defined as a control system sensor the measures the light levels in a space and adjusts the needed electrical lighting demand for the desired lighting levels to complete a task (Dilouie 2011).

PROPOSED ALTERNATIVES

In the section below, potential alternatives are outlined for the depth of the mechanical proposal. Each of these alternatives were briefly discussed and investigated with the AKF Group mechanical engineers, as well as my mentor within AKF Group. Each design proposal will be briefly discussed, as each one of them will be investigated as alternatives, and compared to one another to determine the best and most realistic redesign that can take place.

Alternatives Considered

There are several overarching factors deemed most important for the proposed mechanical system redesign at Pharm Corp. that will be investigated, analyzed and compared between each alternative. Those factors are comprised of energy consumption, overall system upfront and lifecycle costs, impact on the original building layout, and providing an efficient means of thermal comfort for the employees. Options considered for the potential redesign are as follows:

1. *Active Chilled Beams (ACB) with DOAS unit*
2. *Natural Gas Fired Hot Water System*
3. *Condensate Recovery*

Each of the proposed redesign alternatives just listed focus on a specific area of the mechanical system: ACB focus both on the airside and water-side components of the system, the natural gas boiler adds a hot water element to the system, and condensate recovery focuses on the cooling towers within the mechanical system. Each alternative will also be evaluated for LEED requirements, as receiving a certification would be an upside to a potential redesign, as long as the design factors permit. Along with a LEED evaluation, each alternative will be investigated to determine its overall effect on the environmental through emissions. If an alternative is much better on saving energy and cost, but increases the overall emissions, is it truly a better option?

Active Chilled Beams (ACB) with DOAS Unit

The building currently uses DX AHUs, cooled by cooling tower condenser water, to provide designed airflow to each space determined by ASHRAE 62.1-2013 ventilation calculations. Currently, two air-handling units, one for the West and Core and one for the East side of the building, are housed in their own mechanical rooms. This is reciprocated for each floor, resulting in eight (8) mechanical rooms, taking up approximately 7,200 SF or 5% of the overall building footprint. With the ability to reduce the mechanical room size, additional space for the office building will be available for you.

For an active chilled beam alternative, an investigation will be conducted to determine how its proclaimed advantages of 1) allowing for small ductwork and unit sizes, 2) lower sound levels, and 3) using significantly less energy, hold true for Pharm Corp. (Murphy 2011). With the space between the top of ceiling and bottom of structural steel being rather tight and limited, designing the ACB system can hopefully alleviate the congestion within the ceiling, allowing for simpler and more smooth coordination between all trades. A demonstration of what the chilled beam system appears like in a building is shown below.

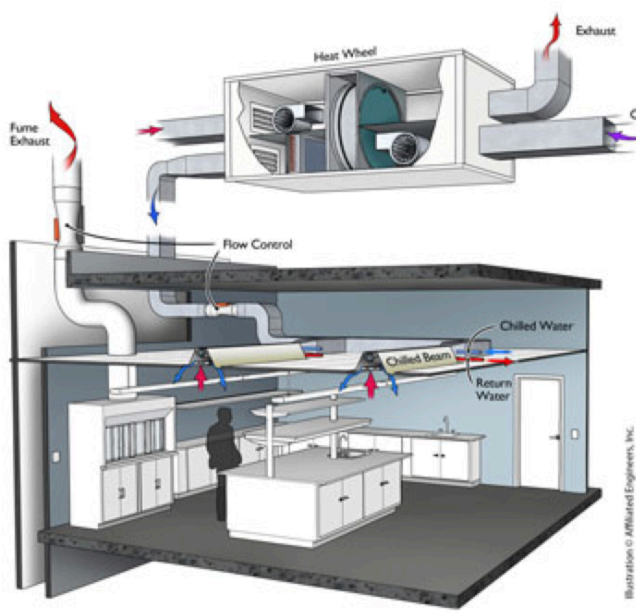

Figure 3. Chilled Beam with DOAS Unit.

With the advantage of smaller unit sizes, the overall mechanical room footprint may be reduced, and can add more office floor space for the owner to utilize. Upon investigation, the goal is to overall reduce the amount of energy that the system uses compared to the variable air volume with electric reheat system that is currently in place. This will be compared to the much larger upfront cost that this system carries, also creating a different life cycle cost and payback period.

With the original system already containing cooling towers and condenser pumps, this will be a retrofit of the existing system. Ideally their current capacities will be enough for the chillers that will have to be installed for the ACB system. This will impact the upfront cost if the redesign has additional costs.

Natural Gas Fired Hot Water System

A natural gas boiler seems an appropriate alternative, as the building currently is an all-electric heat building. This alternative has two avenues that will be investigated: will it either be more efficient to operate the air-handling unit heating coil with hot water and perimeter heating remaining electric, or is it more effective to redesign the entire building to a hot water heating system. As for its economic analysis, the cost of piping and new equipment required will be calculated, to impact its payback period, justifying whether this is an appropriate alternate or not.

Several boiler selections will have to be investigated, to deem a better fit for the building being either a condensing or non-condensing boiler. As a condensing boiler is more efficient, the cost also increases. This alternative also contains the factors that this thesis will be evaluating: energy consumption, thermal comfort control, cost upfront and life cycle cost, and affecting the building footprint layout.

There will be an immediate increase in piping cost for the hot water piping, and a new resource of natural gas will be introduced to the site and energy costs. Investigating to determine by how much it reduces the electric consumption on site, along with determining the new emission factors for this system will be helpful.

Condensate Recovery

With this building being located in Delaware, being a 4A climate zones places the building in a climate that will experience warm, moist temperatures. This climate zone calls for a large cooling load for thermal comfort within the building, and with the present system involving cooling towers, they require a lot of water to satisfy that load. This shows that a condensate recovery system would be of great advantage as an alternative.

As these systems work best in climates with large cooling loads, the use of condensate is valuable. Condensate recovery collects the condensate that runs through the DX AHUs and returns it to the cooling tower as its make-up water, or is stored for later use when the cooling tower demands it. With cooling tower water demand being a factor of the amount of water evaporated, losses due to drift through the fan, and blowdown water removing dissolved solids in the basin water, make-up water must be added for the losses. These terms are illustrated in the Figure 4, on the next page.

The goal of this alternative is to reduce the potable water that must be used within the cooling towers, resulting in a source cost of the water. It will be investigated to see if the current units create enough condensate that can be collected to satisfy the make-up water required for the cooling tower. The alternative system will have little impact on the current VAV system in the building, but can potentially save a lot of water, and save money spent on potable water.

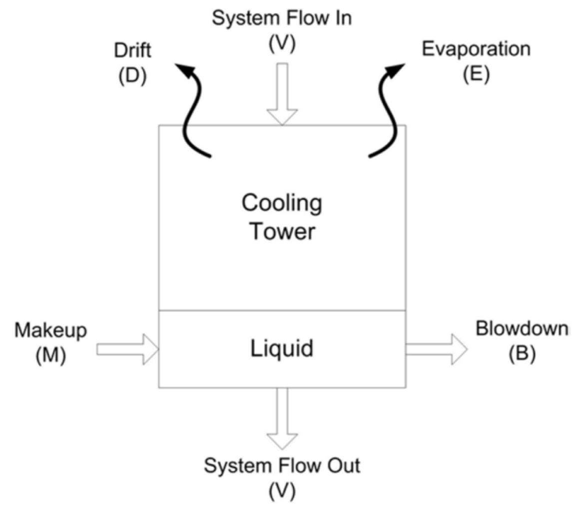

Figure 4. Cooling Tower fluid loss diagram.

A schematic has been created, seen in Figure 5, to illustrate how the condensate is going to be pumped from the air-handling units to the cooling tower. Additional research will be conducted if it is found that there is more condensate recovered than the cooling tower needs at a given time-step.

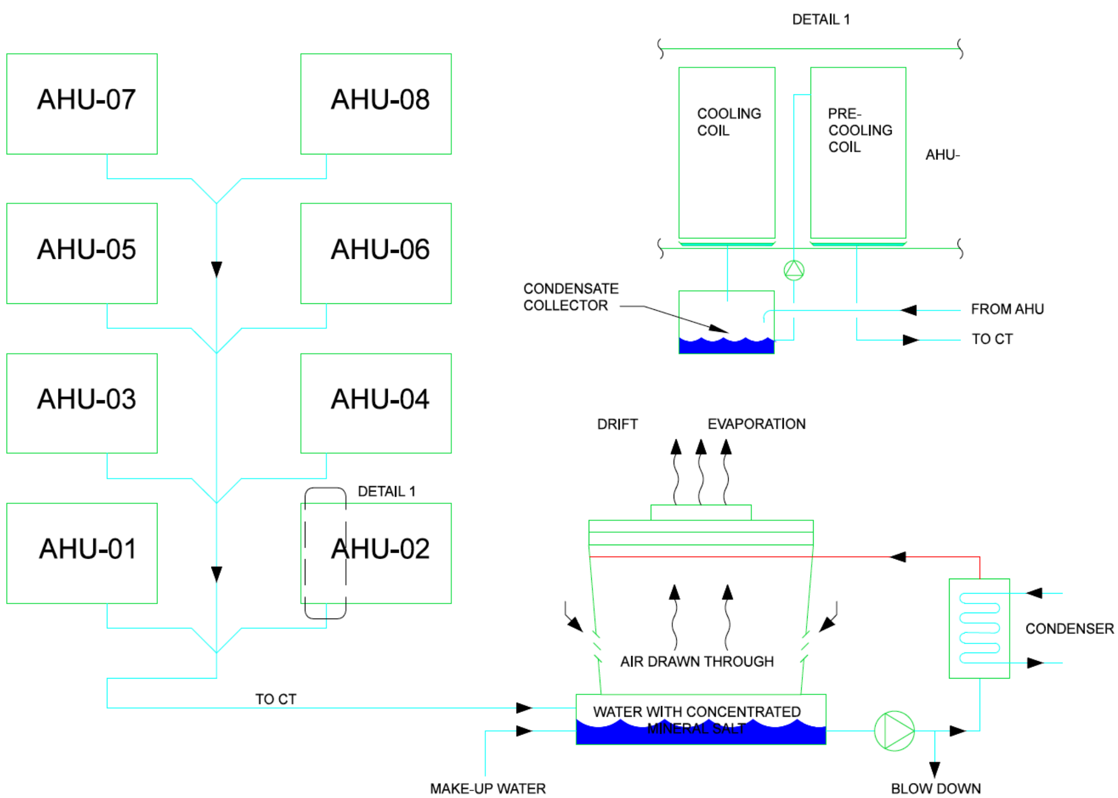

Figure 5. Condensate recovery piping system.

MECHANICAL PROPOSAL

After investigating the three alternatives that were discussed above, a final proposal redesign for the mechanical depth has been decided and discussed below. From the above list, all three alternatives have been chosen to be designed independently of each other, and compared in multiple categories. These categories can be found in the sample table under the Depth section. Following the redesign depth, two breadths have been determined to investigate deeper about each mechanical redesign, as they will be affected and are critically different in each system.

Depth

The main analysis of the mechanical system at Pharm Corp. is evaluating all three alternatives: active chilled beams, natural gas boiler, and condensate recovery. The active chilled beam system is a redesign of both the cooling and heating system, the boiler is a redesign of the heating system, and the condensate recovery is a potential advantage for the cooling tower system. The expected results would be a substantial reduction in energy consumption along with a decrease in emissions. Each alternative will be modeled using Trane Trace 700, and will be compared to the original loads calculated in Technical Report 2.

Each system will have lifecycle cost analyses done, as well as a payback period when looking at the tradeoff between energy savings to upfront costs. These are the determining factors that owners view as the most important. As said above, the table below are the categories that will be evaluated and compared in the mechanical depth of the thesis.

After the model has been created, annual water consumption and electricity usage will be evaluated. Water consumption will be broken down to monthly usages for the overall system, while the electric usage will be divided up by each month for each subcategory expressed in Technical Report 2. Those subcategories are heating, cooling, auxiliary fans, receptacle loads and lighting.

Table 3. Sample table for information to be gathered from each alternative.

System	Cost		Economic Analysis		Emission	Energy	Mechanical Space
	Upfront ($)	$/SF	Payback Period	Life-Cycle Cost	Rates	Cost	Required
Base							
Active Chilled Beam							
Natural Gas Boiler							
Condensate Recovery							

Breadth 1: Electrical Photovoltaics

By designing each of these alternatives and comparing it to the original base design, the largest factor between the designs will be the consumption of energy needed to operate the system fully. The original design is entirely electric heat, which is a large consumer of electricity on the site. As discussed in Technical Report 3, there are incentives and rebates for using certain means of renewable energy, such as solar photovoltaics.

As it will be found out after modeling each system, the electric demands will fluctuate greatly between alternatives. If a solar PV system was to offset the electric demand in the building for each redesign, a different amount of panels will be needed for each design. Economic analysis will be conducted on the cost of solar panels compared to the amount of electricity that can be created.

The solar PV system of each alternative will attempt to reduce energy by 30%, if that is a reachable goal. The reduction in energy goal will be determined once a preliminary solar PV design has been completed. Each alternative will require a different amount of panels to get the same energy reduction, while upfront cost and payback period will differ.

Breadth 2: Potable Water Consumption

A second source that is a variable between the original and alternative designs is the consumption of water. The original design only uses condenser water, while Alternative 1 – ACB uses both condenser, chilled water and hot water, Alternative 2 – Natural Gas boiler uses hot water and condenser water, and Alternative 3 – Condensate Recovery, uses condenser water. This breadth is strictly investigating how each system impacts the water consumption within the mechanical system. Water for plumbing fixtures will remain the same through each system.

Each of the systems will use different amounts of water, and different water temperatures. Analyzing how each system will change its water consumption when both the load in the space shifts, along with the temperature of the water being brought to the space will be conducted. For the chilled beam system, the cooling temperature water is generally higher than chilled water systems, and the hot water is generally cooler than the hot water supplied from the boiler. However, the chilled beams may use more water because of those temperatures. This analysis will be conducted as the second breadth.

PROJECT METHODS

In the section below, there is an outline of the different tools that will be used to execute this project, as well as the determined schedule timeline of work for the project over the following semester. All tools proposed to be used in the execution of this redesign are currently provided by Penn State's Architectural Engineering department.

Tools

The tools outlined below are of the computer software that will be used to evaluate the desired goal factors of energy consumption, cost, impact on the original building layout, and efficiently providing thermal comfort. Each tool will list its function and intended use for the project, as well as its limitations.

Revit

Modifications to the mechanical system will be coordinated within Revit. With the limited ceiling space throughout the building, three-dimensional sections will be able to be created to coordinate the duct location with the structural steel and the mechanical pipes. It will also be able to reduce the mechanical room spaces to show the newly created office space available for use. Loads will not be created in Revit, as there can be errors within the U-values of the wall types created by the architect, differing the results from other load software.

Trane Trace 700

Trace will be used to create new energy models for both the active chilled beam system and the natural gas boiler system. It will determine the efficiency of the system, the overall energy consumption and also the monthly usage, and will be used to size the new mechanical system. These models will then be used to evaluate the life-cycle costs of the redesign alternatives. Comparing the systems within Trace will be difficult, so it will be conducted with other software to view comparisons visually.

Microsoft Excel

Excel will be used for comparing costs between each of the systems, to create graphics as visual representations for comparisons, and will be utilized for any actions that Trace cannot complete. It will be able to track the energy consumption and water consumption of each month for each system. Electric production from the solar panels will also be tracked in Excel, as it is a function of solar intensity and time of year.

Schedule

Below is the thesis work timeline created that will be followed for an efficient means of completing the work in a timely manner, and is subject to change due to potential assignment due dates. The grey vertical bar is spring break, as work will be completely either beforehand or during. Research will be conducted as soon as possible to expedite the schedule, or to allow for potential delays.

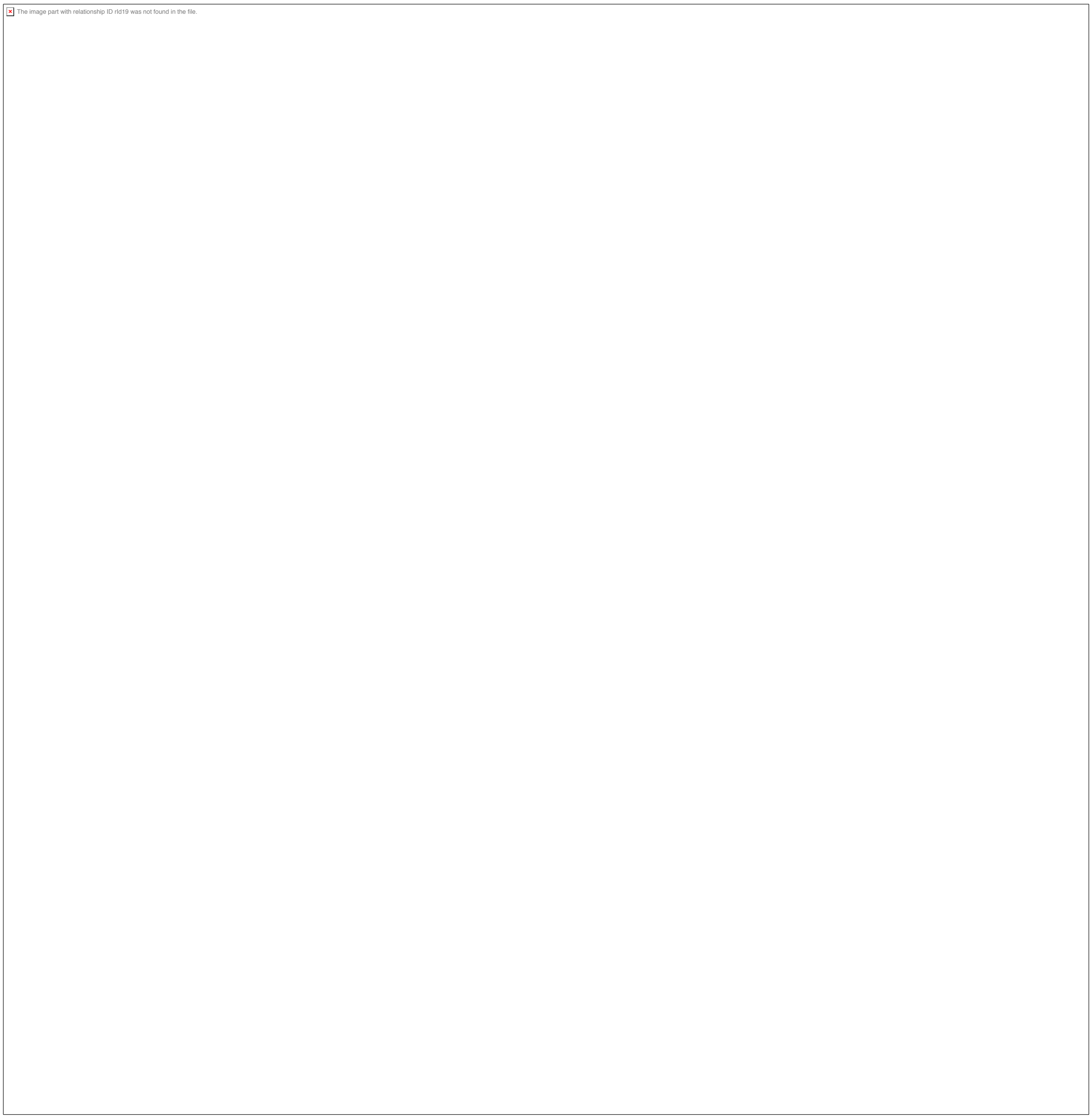

Figure 6. Thesis timeline for workload.

RESEARCH

Below are the preliminary sources for research that was completed to develop the proposal. This list will continually grow as research becomes more in depth.

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ASHRAE (2009). 2009 ASHRAE Handbook - Fundamentals. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

Design Documents provided by AKF Group

LEED-NC Green Building Rating System for New Construction & Major Renovations v2.2

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